Development of Radiation Hydrodynamic code STAR for EUV plasmas

Atsushi Sunahara

suna@ile.osaka-u.ac.jp

Institute for Laser Technology

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Introduction

EUV conversion efficiency consists of three factors.

EUV[1)]Conversion efficiency (CE)

1) 13.5nm wavelength with 2% bandwidth

= **laser absorption fraction** × **X-ray conversion fraction** × **EUV spectral efficiency**

$$\frac{\text{absorbed laser energy}}{\text{input laser energy}} \qquad \frac{\text{x-ray emission energy}}{\text{inputed energy into plasma}} \qquad \frac{\text{EUV emission energy}}{\text{x-ray emission energy}}$$

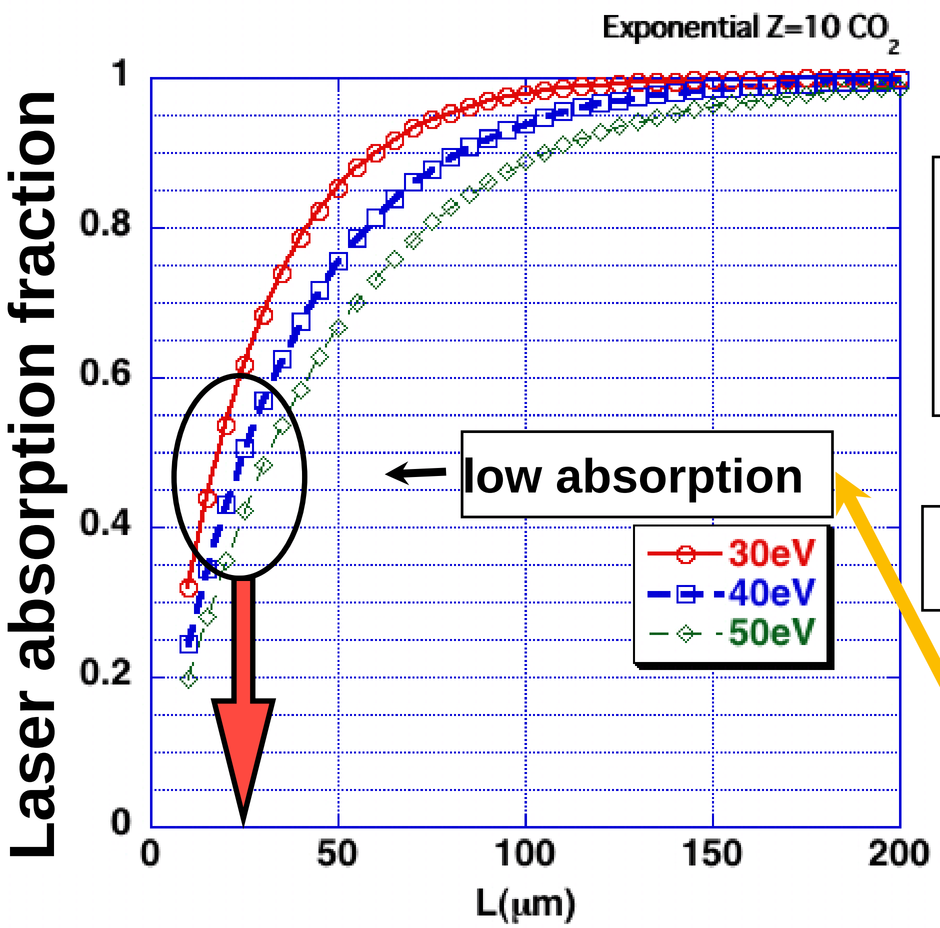
In order to get high EUV CE, we have to maximize the product of three factors.

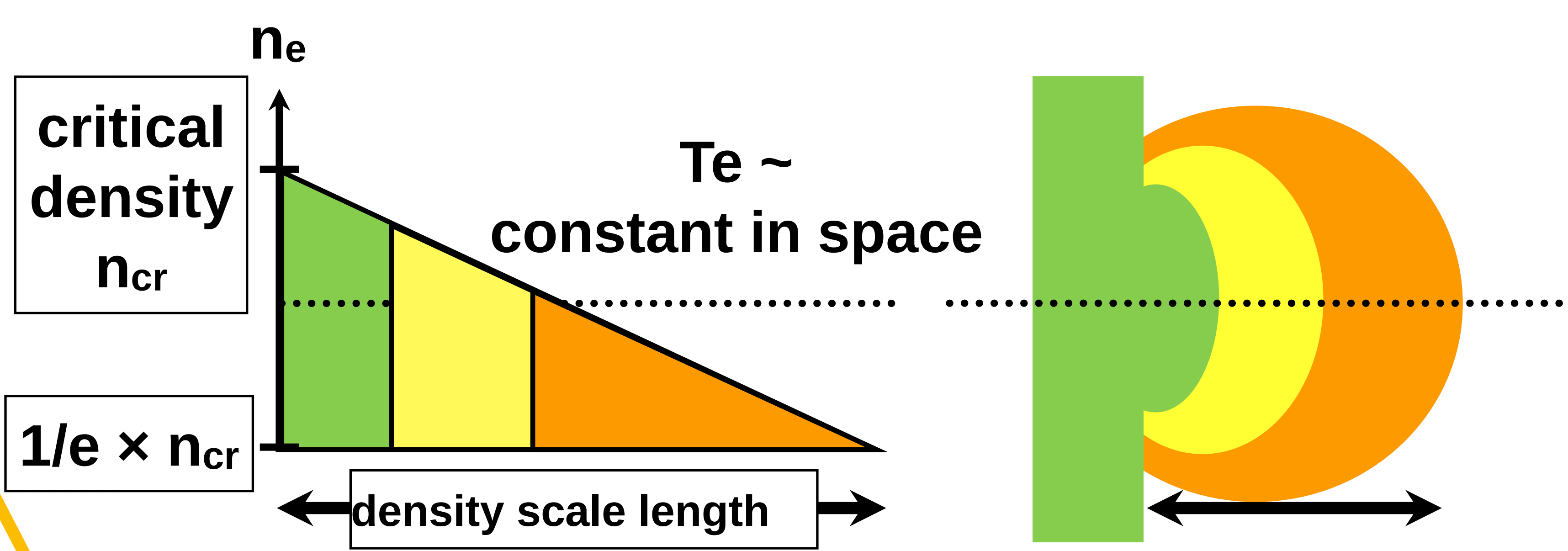
Especially, we pay attention to the laser absorption fraction.

CO_2 Laser :10^{10}W/cm^2, pulse duration:110ns, spot diameter:200μm$^{\Phi}$

(cm) electron density | electron temperature | EUV emission

(cm) | (cm) | (cm)

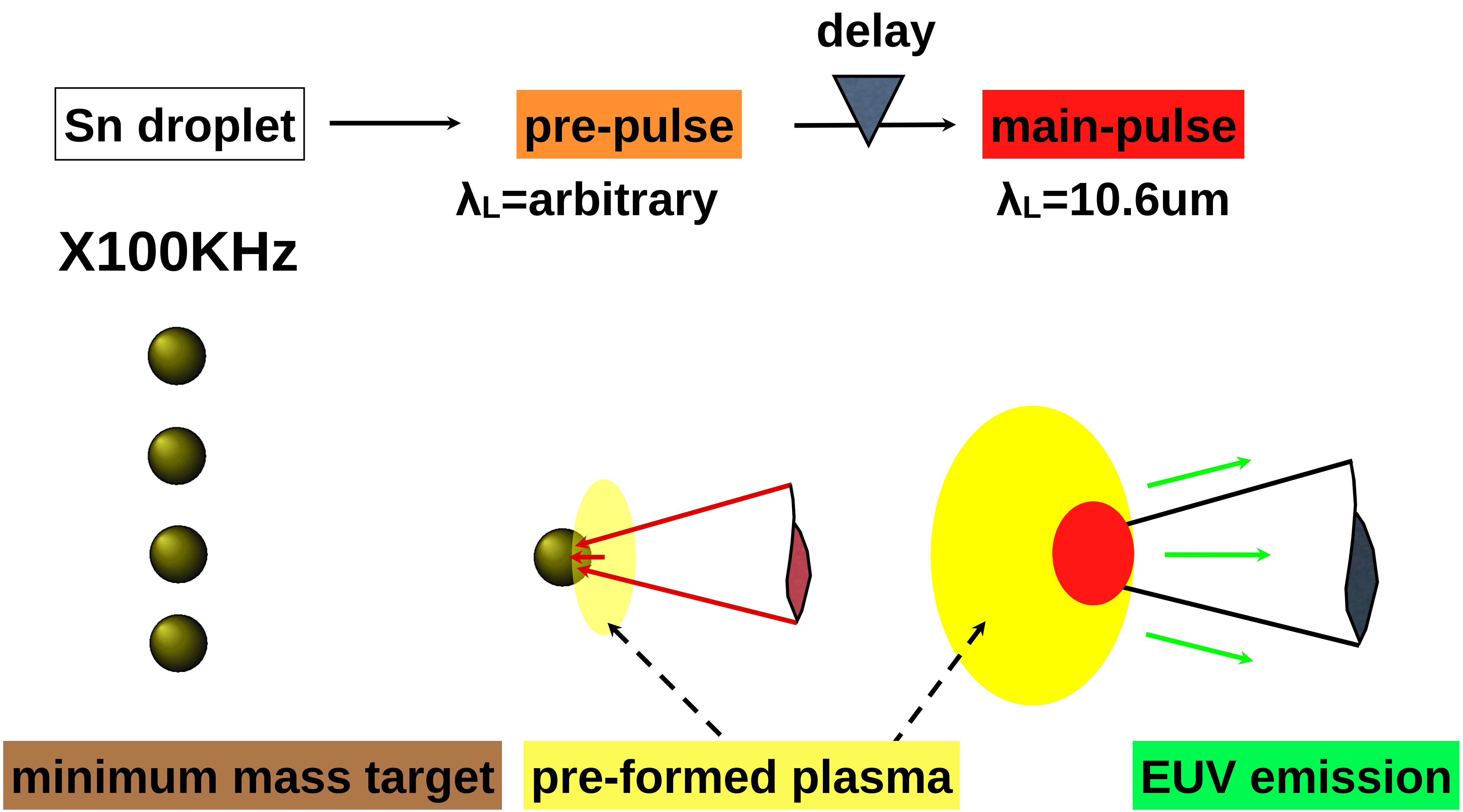




Density scale length keeps 25 μm in time due to the lateral flow from the laser spot.

Double pulse irradiation was proposed to atcheive Efficient, High Power EUV light

Double pulse irradiation scheme



Dynamics of tin droplet is key issue for achieving high CE.

One fluid two temperature model of plasma fluid

Fluid

$$\frac{D\rho}{Dt} + \rho\nabla\cdot\vec{v} = 0$$

continuity equation

$$\frac{D\vec{v}}{Dt} = -\frac{1}{\rho}\nabla(p+q)$$

momentum equation

$$\rho c_{vi}\frac{DT_i}{Dt} = \underbrace{-\left\{T_i\left(\frac{\partial p_i}{\partial T_i}\right)_\rho + q\right\}\nabla\cdot\vec{v}}_{\text{pdV work}} + \alpha(T_e - T_i) + \underbrace{\nabla\cdot(\kappa_i\nabla T_i)}_{\text{ion conduction}}$$

ion energy equation

$$\rho c_{ve}\frac{DT_e}{Dt} = \underbrace{-T_e\left(\frac{\partial p_e}{\partial T_e}\right)_\rho\nabla\cdot\vec{v}}_{\text{pdV work}} - \underbrace{\alpha(T_e - T_i)}_{\text{ion-electron T relaxation}} + \underbrace{\nabla\cdot(\kappa_e\nabla T_e)}_{\text{e conduction}} + S_L + S_{Rad}$$

electron energy equation

Laser

$$S_L = (k_L\cdot\nabla)\cdot I_L$$

Laser heating term

Radiation

$$\rho\frac{D}{Dt}\left(\frac{E_\nu}{\rho}\right) + \nabla\cdot D_\nu\nabla E_\nu = 4\pi\eta_\nu - c\chi_\nu E_\nu$$

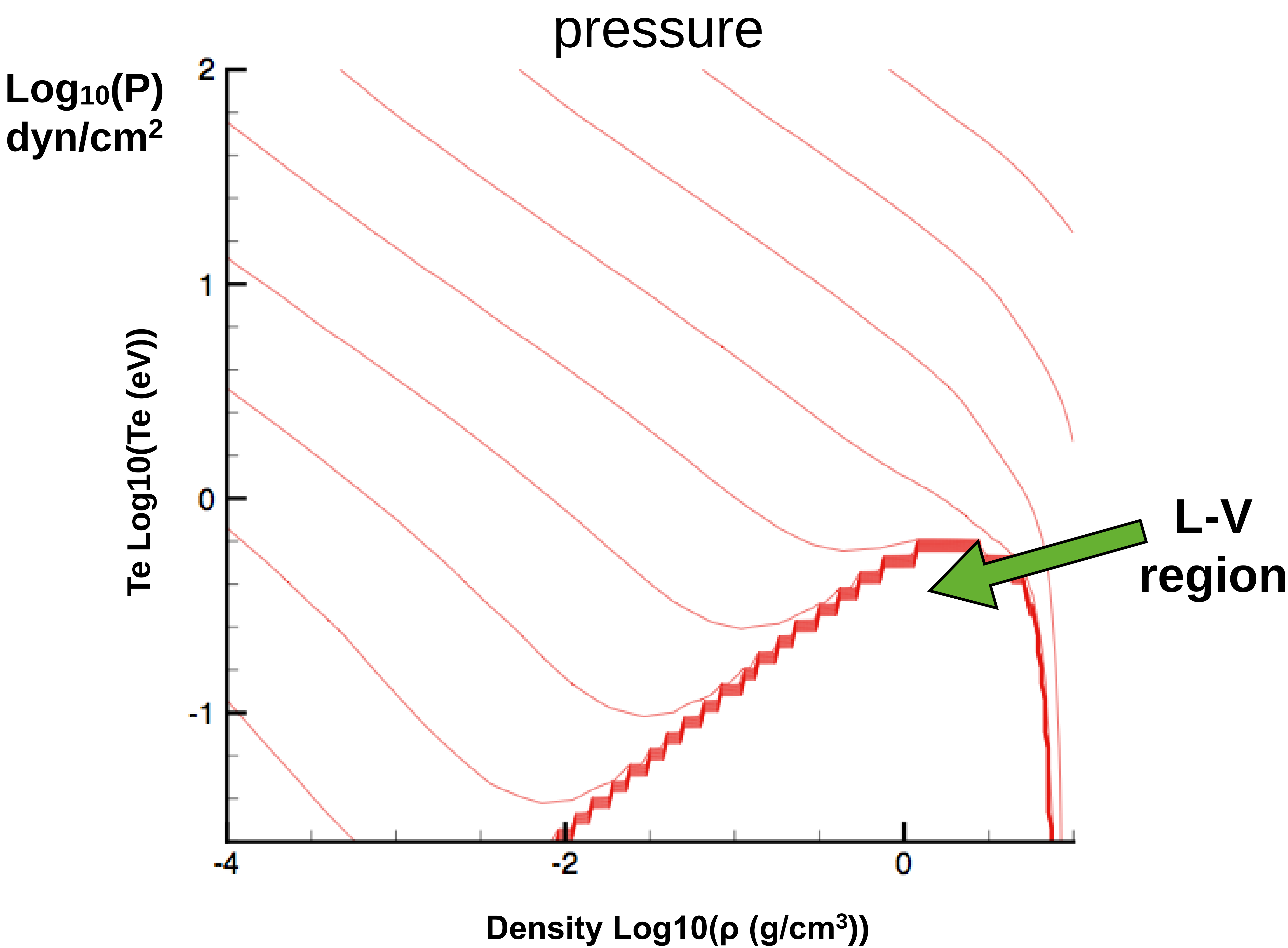
multi-group diffusion approximation

$$S_{Rad} = -\int(4\pi\eta_\nu - c\chi_\nu E_\nu)d\nu$$

Radiation heating term

EOS dependent

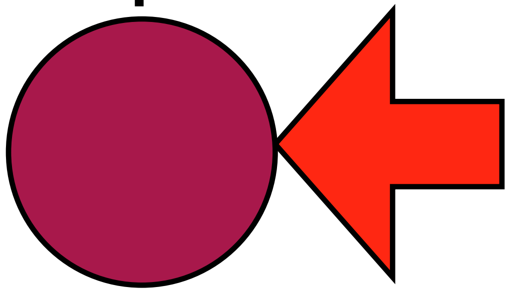
Atomic physics calc. dependent


pressure
Log10(P) dyn/cm2
Te Log10(Te (eV))
2
1
0
-1
-4
-2
0
Density Log10(ρ (g/cm3))
L-V region

STAR1D

Sn Sphere

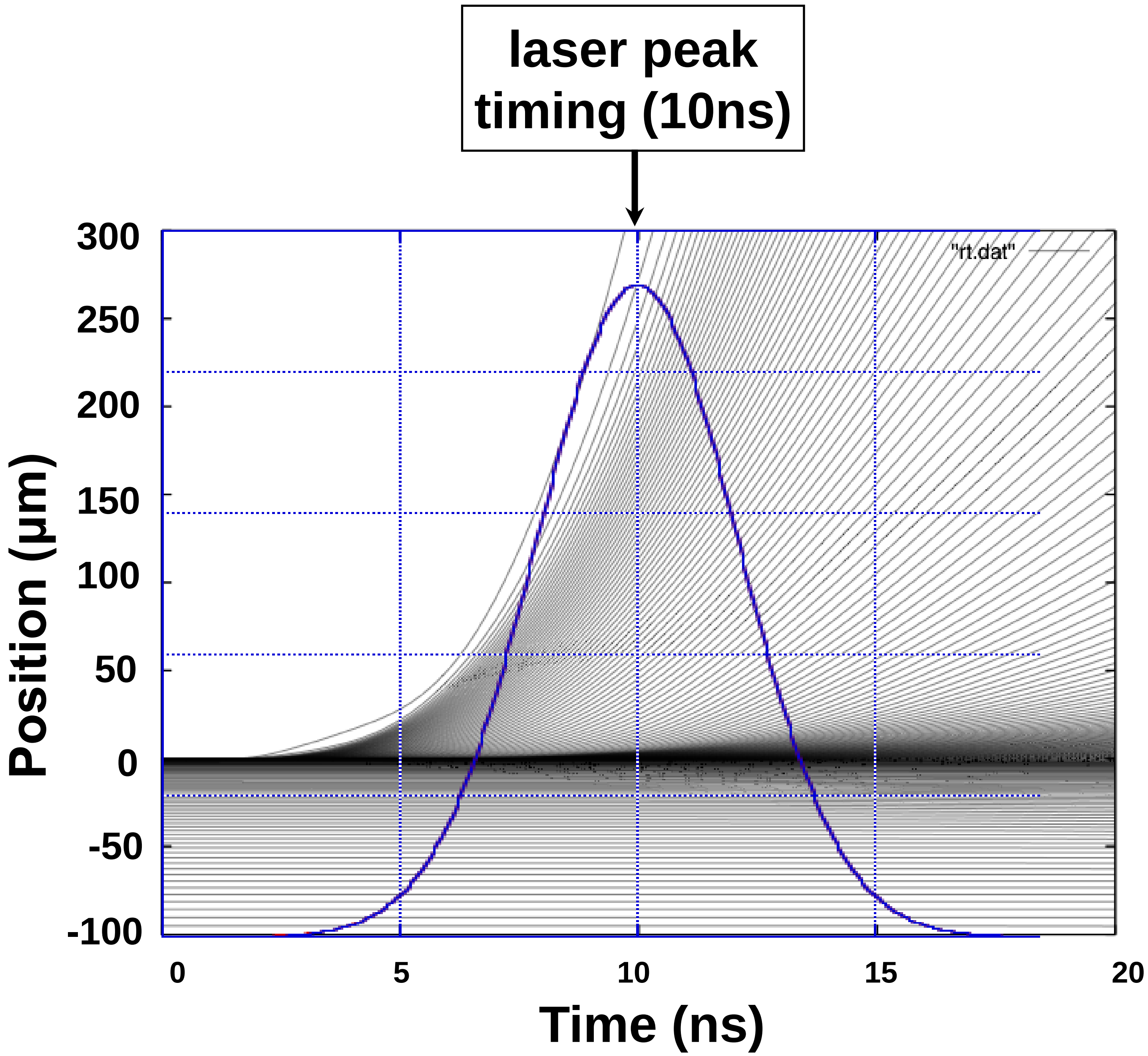
100μm$^{\Phi}$

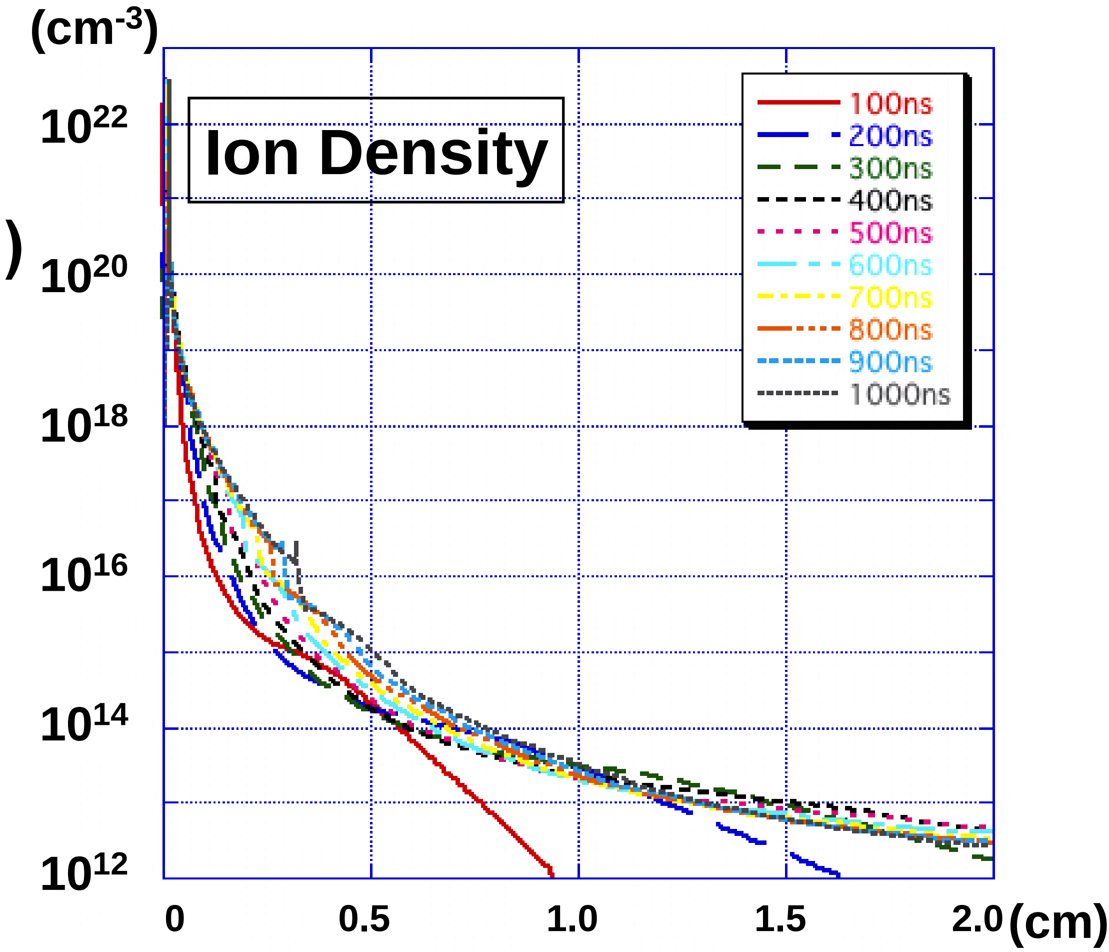


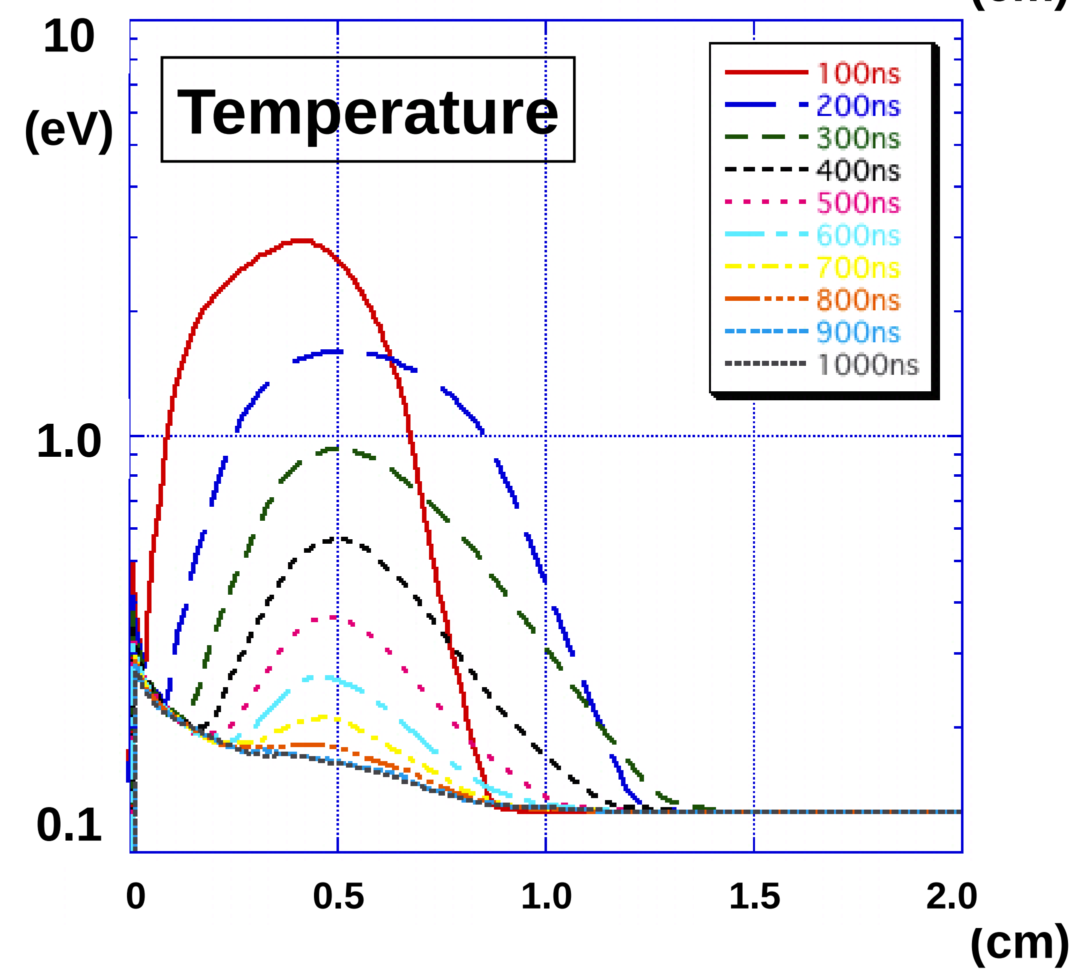
wavelength: 1.06μm

intensity : 5X10^{10}W/cm^2

duration : 5ns (Gaussian FWHM)

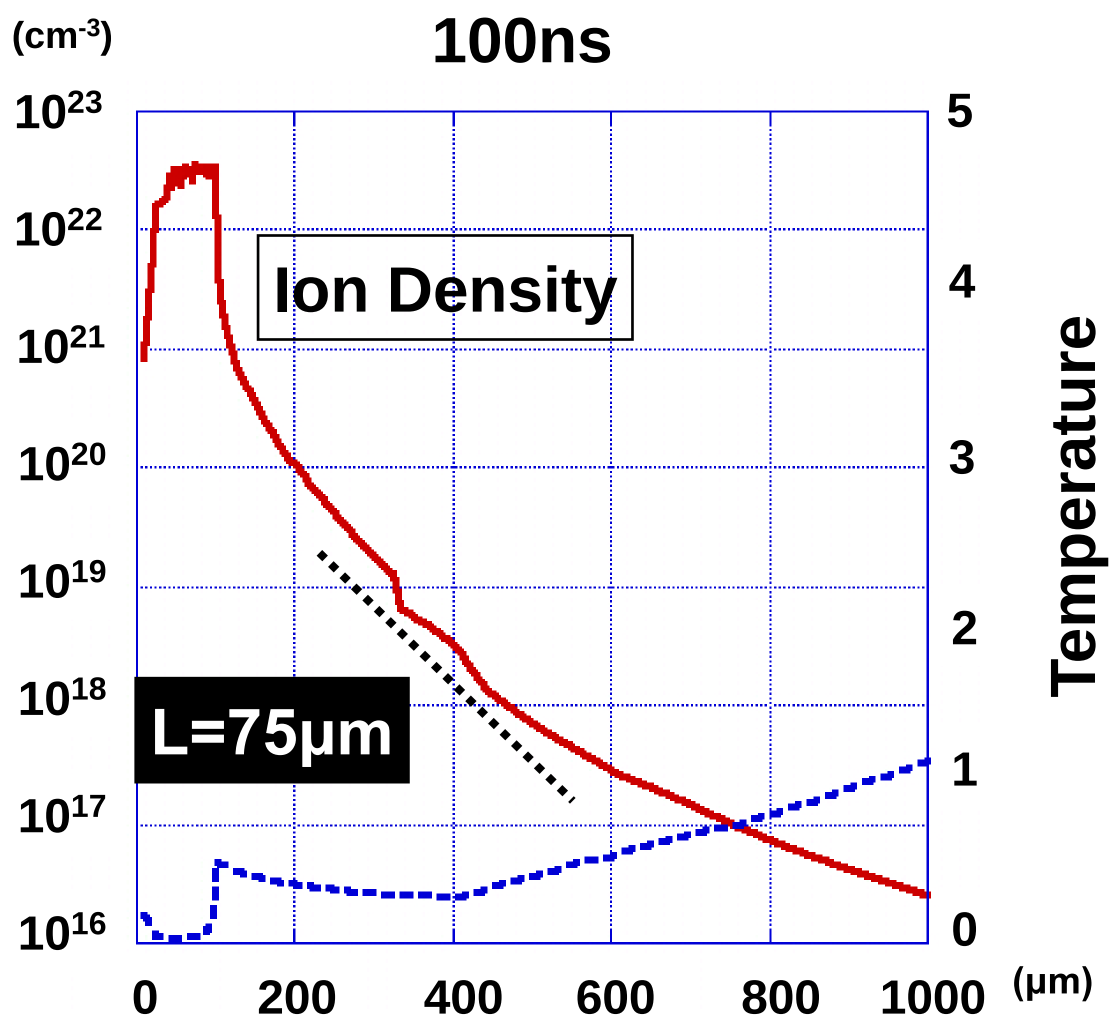


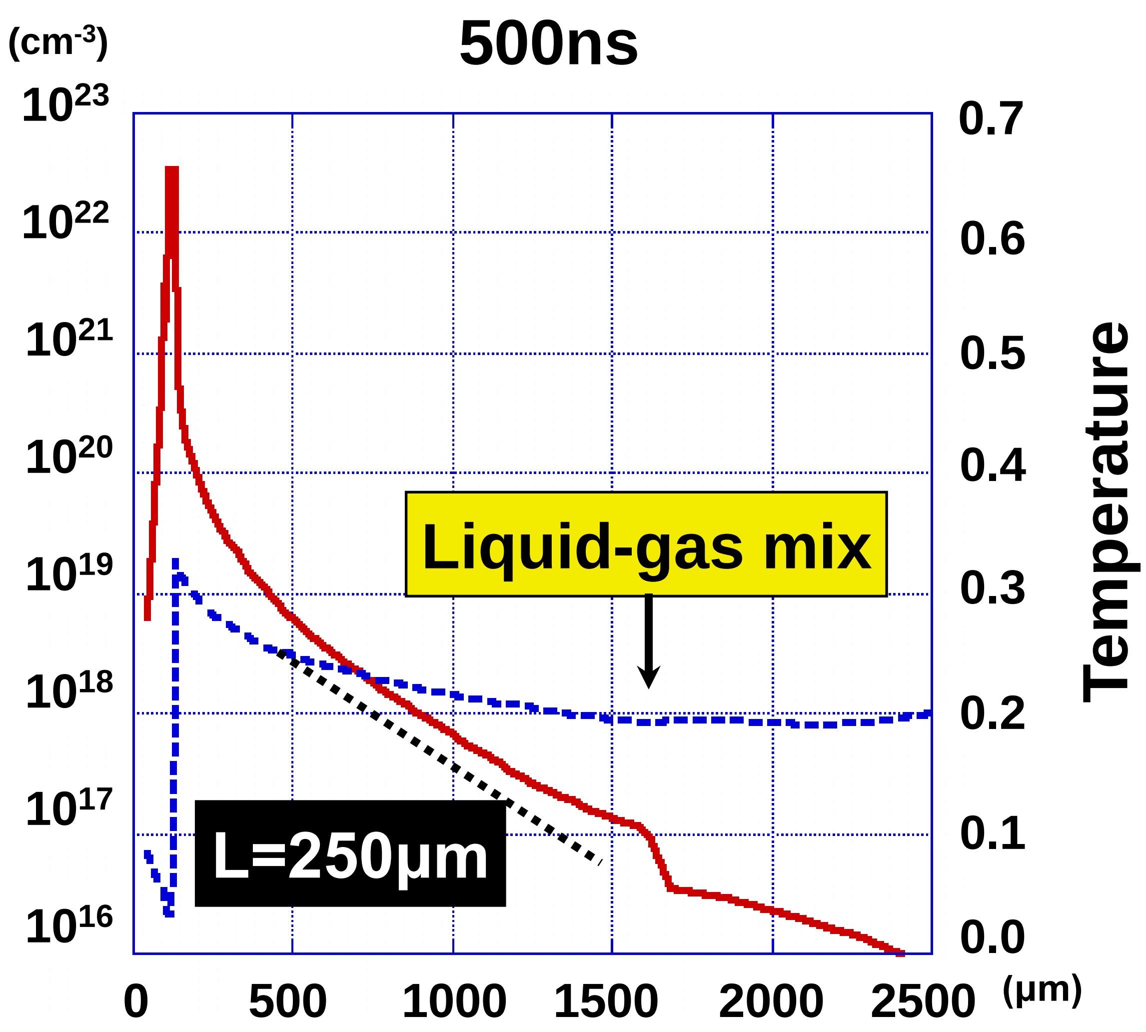




Sn EOS

Sphere (r_0=100μm)





Expanding region can enter in the liquid-vapor mix phase.

2D cylindrical simulation

(cm)

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Microsoft Video 1 êLí£ÉvÉçÉOÉâÉÄ
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(cm) **axis symmetry**

Pressure

dyn/cm^2

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(cm) axis symmetry

Pressure

dyn/cm^2

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(cm) axis symmetry

Density

g/cm^3

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(cm) axis symmetry

Temperature

eV

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(cm) axis symmetry

electron density

(cm^{-3})

(cm)

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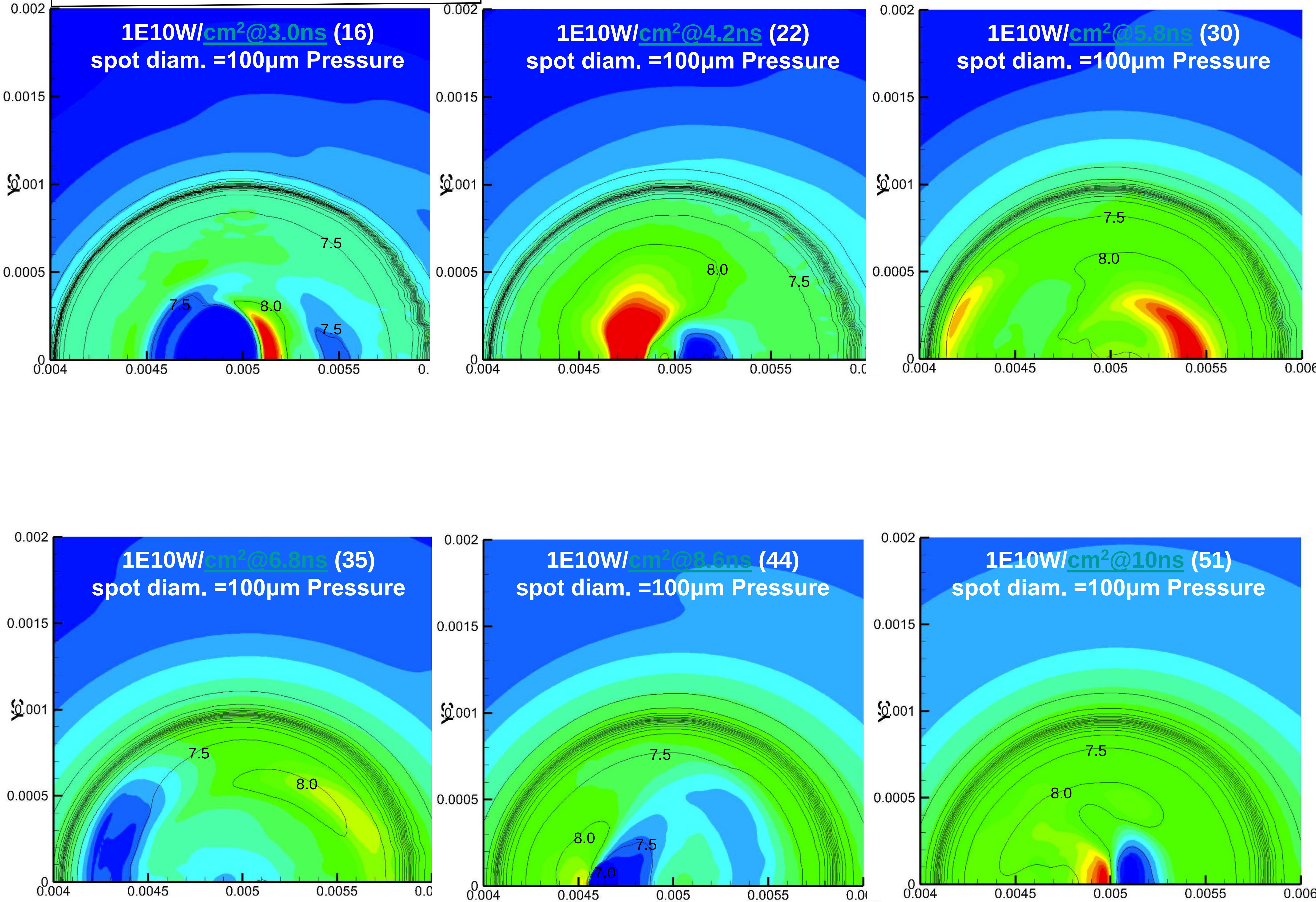
(cm) axis symmetry

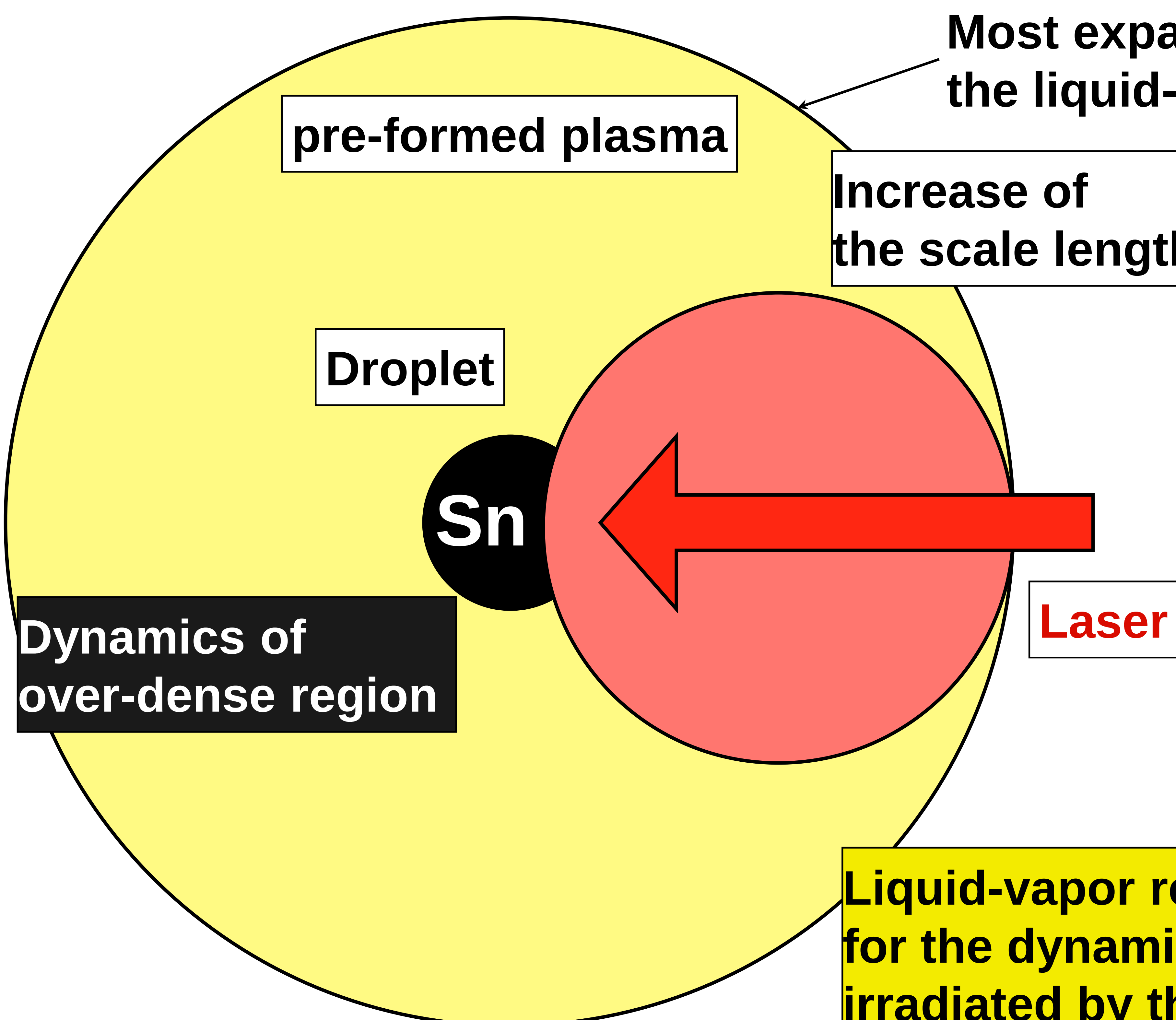
Laser intensity 1×10^{10}W/cm^2

1E10W/cm^2 Spot=100μm



Summary & Conclusion

We simulated the tin droplet irradiated by the 1.06μm nano-second laser.



Liquid-vapor region is very important for the dynamics of tin droplet irradiated by the pre-pulse.